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A Review Of Road–Related Soil Erosion: An Assessment Of Causes, Evaluation Techniques And Available Control Measures

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ABSTRACT

Road construction has increased significantly worldwide in the last decades to meet the demands of the increasing human population and this has led to serious soil erosion problems, the bulk of which is unaccounted for, especially in the developing world. For comprehensive land management decisions and monitoring strategies, a review of work that has been done to assess soil erosion due to roads is critical. This article, therefore, reviews the causes of road–related soil erosion, assessment methods and available control measures. Specifically, this work provides an overview of (i) the linkages between roads and soil erosion; (ii) measurement and prediction of road–related erosion; and (iii) erosion control and rehabilitation techniques. Literature shows that road construction results in hill-slope profile modification; removal of vegetation cover; as well as the formation of steep slopes that are prone to severe erosion. Furthermore, there is a variety of erosion control measures for controlling road–related erosion although no study has demonstrated the method that is cost efficient and operational across different landscapes. We are of the view that this study provides guidance in future research on road–related soil erosion across the developing world where sophisticated monitoring techniques are limited due to resource scarcity for assessing large areas.

Key words: Roadcut and fill embankments, road drainage structures, runoff, soil loss, measurement and prediction, revegetation.

RESUMEN

La construcción de carreteras se ha incrementado ampliamente en todo el mundo durante las últimas décadas para cumplir con las demandas de la creciente población humana, lo que ha llevado a serios problemas de erosión de suelos, muchos de los cuales no se previeron, especialmente, en los países en desarrollo. Sobre las decisiones y supervisión de estrategias de un manejo completo del terreno se realizó una revisión al crítico trabajo que se ha hecho para medir la erosión en suelos causados por las carreteras. Por esta razón, este artículo revisa las causas de la erosión relacionada con la construcción de rutas y evalúa los métodos y medidas de control disponibles. Específicamente, este trabajo ofrece una revisión de (a) las relaciones entre las carreteras y la erosión de los suelos; (b) la medida y la predicción de la erosión vinculada a las carreteras, y (c) las técnicas de control de erosión y rehabilitación. La literatura muestra que la construcción de carreteras produce modificaciones en el perfil inclinación, remueve la vegetación superficial y aumenta la inclinación en pendientes propensas a erosión severa. Además, existen varias medidas para controlar la erosión causada por la construcción de carreteras, a pesar de que ningún estudio ha demostrado el método que sea más eficiente y operacional para diferentes paisajes. Este estudio guía futuras investigaciones en la erosión causada por la construcción de caminos en los países en desarrollo donde las técnicas de supervisión sofisticas para la evaluación de grandes áreas son limitadas debido a la escasez de recursos.

Palabras clave: Diseño de carreteras, llenado de diques, estructuras de desagüe de carreteras, escorrentía, pérdida de suelos, medida y predicción, revegetación.

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INTRODUCTION

Road construction has increased significantly worldwide in the last decades for the provision of effective human mobility and transportation of commodities (Bochet et al., 2010). This development has resulted in permanent alteration of the geomorphic and hydrological settings of the landscape leading to increased soil erosion (Ramos-Scharron and Macdonald, 2007). For instance, road construction can result in the modification of natural hill-slope profiles, the construction of roadcut and fill embankments and impervious roadbeds that concentrate runoff (Jordan and Martinez-Zavala, 2008). Roads concentrate runoff, critical for enhancing increased hill-slope soil loss and sediment yield which later impairs the quality of surrounding open waterbodies (Forsyth et al., 2006; Lane and Sheridan, 2002; Ramos-Scharron and Macdonald, 2007; Sheridan and Noske, 2007). For instance, Lane and Sheridan (2002) in their study observed a water quality deterioration as shown by increased turbidity and total dissolved solids downstream of a road stream crossing. The major sediment source at the road stream crossing was the result of erosion on the road verge and the road fill slopes.

Environmental challenges caused by the accelerated soil erosion due to roads have economic ramifications related to soil rehabilitation and water treatment. It is therefore, a necessity to provide an overview of literature on road-related soil erosion for a better understanding of the causes and methods of assessment that have been considered so as to (1) guide future development; and (2) provide the necessary guidance and informed recommendations on possible efficient and cheap monitoring approaches and erosion control efforts especially in resource-scarce environments. This review therefore seeks to provide an overview of: (i) the effects of armoured roads on soil erosion by water, (ii) related structural designs that facilitate soil erosion processes, and (iii) available approaches for assessing road-related soil erosion and the available erosion control techniques.

So far, to the best of our knowledge, no studies have been done to assess soil erosion related to paved roads. For instance, previous studies on road–related erosion have been dominated by the work on forest roads (i.e. unpaved roads) which include those by Burroughs and King (1989) who addressed the potential for reduction of onsite sediment production by different treatments on various components of the forest road prism. Croke and Hairsine (2006) reviewed the interaction of forest road and track network with both sediment and runoff delivery in managed forests. The study by Macdonald and Coe (2008) discussed the underlying processes of forest roads sediment production from surface erosion and land sliding. Although Baird et al. (2012) also reviewed forest road erosion, their focus was on the processes of erosion and sediment delivery from these roads, whereas the other studies either considered land sliding or the process of runoff from the forest road network only. The limitation of the reviews mentioned above is that none addressed the post-construction case of armoured roads except focusing on erosion from unpaved forest roads. Furthermore, none of the studies conceptualized assessment of road-related erosion, as well as its control.

ROAD-RELATED SOIL EROSION

Road construction creates numerous roadcut and fill embankments, as well as ditch relief or culvert sites (Figure 1) that contribute to runoff and high sediment production that cause extreme land degradation (Ramos-Scharron and Macdonald, 2007). Roadcut and fill embankments have bare and steep gradients that cause the generation of runoff and sediment yield (Bochet and García - Fayos, 2004). Lack of vegetation cover also intensifies soil detachment by raindrops and proliferates susceptibility to erosion as a result of reduced cohesion and shear strength of the soil (Jankauskas et al., 2008). Similarly, steep gradients increase erosion on these slopes due to reduced water infiltration and increased runoff accumulation (Arnaez et al., 2004; Cerdà, 2007).

Numerous studies have documented soil erosion on roadcut and fill embankments (Arnaez et al., 2004; Jordan and Martinez-Zavala, 2008; Megahan et al., 2001; Xu et al., 2009). For example, a study by Arnaez et al. (2004) recorded a significant generation of runoff and sediment from roadcut embankments and fill slopes in the Iberian Range, Spain. Roadcut embankment soil loss rates exceeded those from the fill slopes by 16 times, and this was attributed to the steep gradients, presence of embedded gravels and low vegetation cover. Similarly, Jordan and Martinez-Zavala (2008) recorded a total soil loss of 106 g m^{-2} and 17 g m^{-2} from roadcut and side-cast fills respectively in southern Spain. The highest erosion rate was observed on the roadcuts due to steep slopes, low vegetation cover and the presence of loose colluvium. Moreover, Megahan et al. (2001) evaluated the effects of slope gradient, slope length, slope aspect, rainfall erosivity and ground cover density on erosion on the roadcuts in Idaho, USA. The multiple regression analysis showed that slope gradient was the most significant of all site variables in affecting roadcut erosion. Xu et al. (2009) on the other hand investigated the effects of rainfall and slope length on runoff and soil loss on the Qinghai-Tibet highway side-slopes in China and found that rainfall intensity correlated with sediment concentration and soil loss, while soil loss decreased with increasing slope length. In summary these studies highlight that slope properties (viz. slope gradient and length, vegetation cover and soil properties, particularly soil texture) of the roadside embankments are critical in determining the degree of soil erosion along these areas.

Roads initiate soil erosion through drainage structures diverting water from their impervious surfaces as well as from roadcut embankments. Road surfaces (including unpaved roads) increase runoff generation (Ziegler and Giambelluca, 1997). Furthermore, the road surfaces transect the hillslope hydrology, creating the need for draining the roadcut embankment and road surface through culverts at regular intervals (as indicated by point 1, in Figure 1), with the consequential change from diffuse surface flow downslope to concentrated flow. Extensive surface erosion may occur where this concentrated flow is discharged down-slope at discharge points (point 2 and 3 in Figure 1). Geomorphic impacts of concentrated runoff from road drainage have been documented by numerous studies (Jungerius et al., 2002; Kakembo, 2000; Montgomery, 1994; Beckedahl and de Villiers, 2000).

Montgomery (1994) conducted a field survey of road drainage concentration in the western United States and observed that the discharge of road surface concentrated runoff and of intercepted subsurface flow result in initiation and enlargement of a gully and slope instability below the drainage outfall. Gully initiation was related to ground slope and contributing area thresholds. Kakembo (2000) reported a case of ephemeral stream incision triggered by runoff concentration through a series of railway culverts on a steep hillslope at Kwezana, Eastern Cape, South Africa and concluded that concentrated runoff coupled with the steep slope of the drainage discharge area and the rainstorms of high magnitude influenced gully initiation. Although not a case study of roads, the scenario is similar in this instance too, the slope hydrology is disrupted and concentration of runoff initiated gullies and triggered hillslope instability. Jungerius et al. (2002) reported gully formations where concentrated surface water was diverted to the verges alongside the road in West Pokot, Kenya. The study found that gully formation is influenced by the steep slopes, lack of vegetation cover, torrential rainfall and the fine grained soils of the alluvial fans. Beckedahl and de Villiers (2000) investigated the causal relationship between road drainage and pipe erosion in the Eastern Cape province, South Africa. Their findings showed that soil pipes and gullies developed where road drainage resulted in a high concentration of surface water on sensitive or dispersive soils. These studies have shown that erosion initiation at road drainage discharge sites is influenced by the contributing area, slope steepness, rainfall intensity and soil properties. The studies by Kakembo (2000) and Montgomery (1994) however, did not include the estimation of the quantity of soil loss in their agenda. Investigations of the impact of concentrated road runoff on soil erosion, to be complete and comprehensive, should also consider an estimation of the amount of soil loss rather than simply focussing only on the contributing factors. These estimations are necessary as they could provide a clear and detailed evidence of the effects of concentrated road runoff discharge on the actual soil loss.

After analysis of the possible impacts of road construction on soil erosion, it is important to highlight the methods that can be used to investigate road–related erosion. This knowledge will help for accurate assessment of erosion levels and soil loss along the road networks.

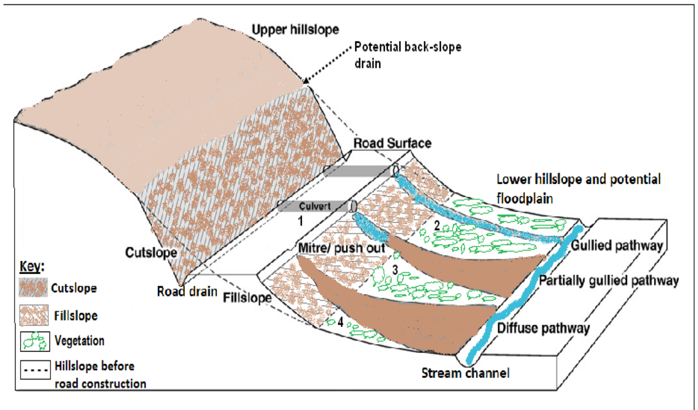

Figure 1. A typical cut and fill road cross section and features. The numbers one (1) to four (4) refer to potential impacts, and these are discussed in the text. Adapted from (Fu et al., 2010).

METHODS OF ASSESSING ROAD–RELATED SOIL EROSION

Road–related soil erosion field measurement techniques

Available field methods of measuring road-related erosion have been principally based on rainfall simulation and volumetric surveys of erosion features. The choice of a particular technique primarily depends on the part of the road component that will be monitored (Table 1). For instance, rainfall simulation method has been widely used to explore runoff and soil loss processes related to roadcut and fill slopes, as well as unpaved road surfaces in many parts of the world (Table 1). Rainfall simulators create controlled rainfall events (Jordan and Martinez-Zavala, 2008), and their design depends on the type of experiments to be carried out (Clarke and Walsh, 2007). Control of rainfall allows determination of the relationship between soil loss and rainfall parameters (Lascelles et al., 2000) as well as generation of runoff and soil loss under repeatable conditions (Hamed et al., 2002). Moreover, in semi-arid regions, with high rainfall variability and recurrent droughts, rainfall simulation could be useful (Cerdà, 2007). However, rainfall simulation is uncertain for extrapolating results to larger scale (Arnaez et al., 2004) and also underestimates soil loss as compared to natural rainfall as it supplies a constant rainfall intensity (Boix-Fayos et al., 2006) and short duration rainfall (Jin et al., 2008). Nevertheless, simulation results remain useful for comparative purposes (Foster et al., 2000; Jordan and Martinez-Zavala, 2008) and for planning, despite challenges of underestimating soil loss and limitation to small scale applications.

On the other hand, the volumetric survey of erosion features for assessing road-related soil erosion involves the use of measured dimensions (viz. lengths, widths and depths) of the erosion features either directly in the field or from the use of photographic images to estimate soil loss (Okoba and Sterk, 2006). These dimensions are then utilized to calculate the volume of the erosion features excavated, which is equivalent to the volume of soil lost (Hagmann, 1996). Although actual soil loss is underestimated since inter-rill erosion is excluded when measuring pipe, gully, and rill erosion, the approach produces the best approximation of erosion (Bewket and Sterk, 2003). A number of studies have been carried out using the volumetric survey of erosion features to estimate soil erosion on roadcut and fill embankments and most of these have focused on measurement of erosion related to concentrated runoff from road culverts (Table 1). Other studies used an erosion index for rill and gully erosion to determine its severity on motorway slopes, such as that of Bochet and García-Fayos (2004), in Valence, Spain. The erosion index is based on the percentage cover of erosion on the sampling area. However, unlike other studies based on quantitative estimation of erosion, this semi-quantitative approach did not reveal the effect of aspect on erosion intensity and this was attributed to the fact that this method might not be precise enough to detect such differences. Although field methods provide the necessary understanding of erosion processes, the obtained results are, however, difficult to generalize due to the complex interaction of erosion processes and field conditions (Ande et al., 2009). Prediction of road-related erosion could, therefore, help consider the complex interactions that affect erosion rate.

Modeling of road-related soil erosion

Soil erosion models vary from simplified procedures, such as the Universal Soil Loss Equation (USLE) to more complex methods requiring a series of input parameters, such as Water Erosion Prediction Project (WEPP) (Oliveira et al., 2012). USLE, and its modifications, the Revised Universal Soil Loss Equation (RUSLE) computes the average annual soil loss caused by rill and inter-rill erosion by multiplying the natural factors (rainfall erosivity-R, erodibility-K, slope length and steepness-LS) and anthropogenic factors (cover and management-C, and conservation practices-P) (Angima et al., 2003; Oliveira et al., 2012). Literature has shown that USLE/RUSLE approaches give better estimates of erosion on an overall basis. For instance, Oliveira et al. (2012) stated that the USLE/RUSLE provides a right approach for soil loss prediction since it is applicable in terms of required input data, and the obtained soil loss estimates are reliable. However, the use of this model is based upon erosion rates from landscapes larger than road plots hence application for roads is at a smaller scale than for which it was intended (Riedel, 2003).

In contrast to the USLE/RUSLE, the WEPP model was developed to provide a spatial and temporal distribution of soil loss (Baird et al., 2012; Clinton and Vose, 2003). This model utilizes climate, infiltration, water balance, soil chemistry, plant growth and residue decomposition, tillage and consolidation to predict soil erosion deposition and sediment delivery (Baird et al., 2012; Clinton and Vose, 2003). WEPP model is applied to roads by including multiple road features such as road surface, cut-slope, ditch, fill slope and lower hillslope (Fu et al., 2010; Cheng et al., 2013; Elliot et al., 1995; Forsyth et al., 2006). The road features are modeled separately by defining them as different overland flow elements with unique soil and vegetation parameters assigned (Fu et al., 2010). Although some models exist for predicting road-related erosion, these are primarily used to predict erosion from the road surfaces (Forsyth et al., 2006; Sheridan et al., 2006) and few studies have focused on modelling erosion on roadside slopes and erosion due to road drainage ditches/culverts (Elliot and Tysdal, 1999; Megahan et al., 2001) (see Table 2).

Erosion models, however, suffer from a range of problems (Barrett et al., 1998). Firstly, the model development was often based on data derived from the United States or European conditions and the application of these models to different climatic and management conditions in other regions has not yet been fully established. Secondly, the models were created for field plot scale, and application for large scales is still questionable. Thirdly, the model predictions are not entirely accurate as a result of incomplete knowledge of the entire set of aspects and interaction processes arising from a limited set of variables. For instance, the disturbance associated with construction frequently exposes the subsoil (or new soil may be brought in from elsewhere) hence the erodibility values along the road will differ to those of the region (Barrett et al., 1998). Therefore, for road applications, these models still require further testing, and modifications to include additional factors specially designed for road erosion (Fu et al., 2010). Measurement of soil erosion using the volumetric survey of erosion features, therefore, could provide a reasonable estimation of erosion (Sidle et al., 2004) and does not involve expensive instrumentation, long lead times and/or sophisticated modeling (Bewket and Sterk, 2003).

Table 1: Overview of the techniques of field measurement of road-related erosion used to date

Road erosion source	Technique	Study Location	Main findings and conclusion	Reference
Cut and fill slopes, and roadbed	Rainfall simulation	Iberian Range, Spain	Erosion measured for cut and fill slopes were consistent with the rates measured using other techniques such as erosion pins. Rainfall simulation, however, provided limited information because of the small size of the plot. Nonetheless, the results allowed comparisons of runoff data and erosion in two sectors of the roads; and their relationship with soil properties.	Arnaez et al. (2004)
Road batters	Rainfall simulation	New South Wales, Australia	Rainfall simulation demonstrated significant fluctuations in soil loss with time from the road batters investigated, and this was attributed to micro-erosion processes. However, the small-scale rainfall simulation could not replicate large-scale erosion processes hence are deemed unsuitable for erosion studies on roads.	Selkirk and Riley (1996)
Road culvert	Volumetric survey of soil pipes	Eastern Cape province, South Africa	Volumetric survey of soil pipes allowed the estimation of the removed soil material. The results, however, are approximations, given the inferences made in obtaining them.	Beckedahl and de Villiers (2000)
Cut and fill slopes	Rainfall simulation	Southeastern Australia	Sediment generation rates from rainfall simulation were consistent with the findings from other studies.	Sheridan et al. (2008)
Cut and fill slopes	Volumetric survey of gullies	Northern Yunnan Province, China	Provided a simple method for estimation of soil loss from cut and fill slopes although errors in the range of ±10% are likely and could lead to underestimation.	Sidle et al. (2011)
Road Culvert	Volumetric survey of roadside gullies	West Pokot, Kenya	Survey of roadside gullies provided a tool that allowed both the estimation of the volume of soil lost due to concentrated road runoff and correlation of soil loss to site variables.	(Jungerius et al., 2002)

Table 2: Mathematical models used for predicting road-related erosion

Erosion source	Model	Study Location	Main findings and conclusion	Reference
Roadcut embankments	USLE	Idaho, USA	The equation allowed the evaluation of factors that affect roadcut embankment erosion e.g slope gradient, slope length, slope aspect, rainfall energy, cover, erosion control practices, erodibility and age of the roadcut embankment. The prediction equation could provide a useful tool to land managers to evaluate the risk of roadcut embankment sediment yield for alternative road design practices.	(Megahan et al., 2001)
Ditch, roadcut embankments, and roadsurfaces	WEPP	Oregon coast range, western Eugene	WEPP predictions were in close agreement with the observed sediment yield measurements. Although WEPP overestimated erosion in some instances, the predictions give a reasonable approximation of sediment yield.	(Elliot and Tysdal, 1999)
Road surfaces	WEPP	New Hanover, South Africa	The model performed well in predicting sediment loss from the road segments. However, the model was unable to account for vegetation cover. Additionally, the model dealt with individual road segments and not the entire road network. Therefore, predicting the entire road network by analyzing individual road segments was complex and time consuming. Nevertheless, WEPP was considered suitable for erosion prediction, although not ideal.	(Moodley et al., 2011)
Cut and fill slopes	WEPP	Southern Appalachian	The predicted average annual sediment yield was within the range of observed sediment yield values. While, the model over-predicted sediment yields in some instances, the relatively high model efficiencies that ranged from 0.51- 0.99 showed that the model was adequate in describing sediment yields observed in the field experiment.	(Grace III, 2005)

METHODS USED TO CONTROL ROAD-RELATED SOIL EROSION

Soil erosion control measures, i.e. non-engineering and bio-engineering (e.g., vegetation, soil erosion control blankets, silt fences and geotextiles) and engineering techniques (e.g., diversion drains and Lattice) are formulated to reduce accelerated soil erosion rates on roadside slopes (Rickson, 2006; Xu et al., 2006). This is because roadside slopes have been demonstrated as major contributors towards road-related soil erosion, accounting for 70 to 90% of the total soil loss from the disturbed roadway area (Grace III, 2000). Most of the erosion control measures are specifically designed to minimise the contact of rainfall with the soil as well as reduce runoff velocity (De Oña et al., 2009). While these soil erosion control methods are effective in minimising road-related soil erosion, however, some of these methods are failing to meet their intended objectives while others are even expensive to use especially in resource-scarce environments.

Amongst all these control methods, vegetation cover is probably the most widely used measure for controlling erosion on roadside slopes (Xu et al., 2006). This is because vegetation cover intercepts rainfall and increases water infiltration (Claridge and Mirza, 1981; Faucette et al., 2006), stabilizes the soil with roots that hold soil particles together (Bochet and García- Fayos, 2004; Collison and Anderson, 1996), and moderates and dissipates the energy exerted by water (Lal, 2001; Ande et al., 2009). Grace III (2000) and Xu et al. (2006) emphasised the importance of vegetation cover in reducing soil erosion and their findings are also supported by the inserts (Figure 2) that indicate the importance of vegetation cover on roadside slopes. Grace III (2000) observed a reduction in sediment yield by over 30% on vegetated roadcut and fill slopes compared to the bare roadside slopes and concluded that vegetation has the greatest potential to mitigate soil erosion through stabilizing the roadside slopes. Similarly, Xu et al. (2006) found that vegetation provided a long-term soil erosion control on roadside slopes and concluded that soil erosion is significantly reduced when vegetation cover is well established.

The effectiveness of vegetation cover to control erosion, however, starts when the vegetation is established (Rickson, 2006) and mature (Vishnudas et al., 2006). For instance, Vetiver grass (Vetiveria zizanioides L. Nash) application significantly controls soil erosion and stabilizes the slopes, although it may take at least one year to become fully effective (Sanguankaeo et al., Guangzhou, China). This implies that a site may be susceptible to erosion during the period when there is no vegetation or immature stage, also making the establishment of vegetation difficult, since there is no immediate and adequate protection (Vishnudas et al., 2006). Additionally, the absence of initial binding material in the slope soils may result in poor vegetation growth (Bhattacharyya et al., 2008). For these reasons, soil erosion control blankets and geotextiles are short-term vegetation cover replacement that have been used to offer immediate soil protection (Smets et al., 2009).

Erosion control blankets reduce runoff and soil erosion by improving soil quality (Bhattarai et al., 2011) and enhancing vegetation (Faucette et al., 2006) that would offer a permanent erosion control. Likewise, geotextiles control rain splash and runoff (Bhattacharyya et al., 2010) and promote a micro-climate for subsequent vegetation growth (Sutherland and Ziegler, 2006). Geotextiles are applied on bare slopes after spreading seed mixture for long-term erosion protection (Sutherland and Ziegler, 2007). Erosion control geotextiles are made from natural or synthetic material (Smets et al., 2009) with synthetic geotextiles dominating the commercial market (Jankauskas et al., 2008). Synthetic geotextiles such as silt fences are used for highway and other construction projects to provide a temporary sediment control (Barrett et al., 1998). Silt fences reduce runoff velocity and filters sediments thereby enhancing sedimentation (Barrett et al., 1998). Silt fences are preferred because they are cheap and easy to install (Robichaud et al., 2001; Wachal et al., 2009). The limitations of synthetic geotextiles, however, are that they are non-degradable and may cause soil pollution, and their production may cause air and water pollution (Bhattacharyya et al., 2010). According to Jankauskas et al. (2008), however, natural geotextiles constructed from organic materials are more efficient in controlling soil erosion since they adhere to the surface's microtopography and can follow slope contours and stay in close contact with the soil (Bhattacharyya et al., 2010). Additionally, natural geotextiles are easily available in many parts of the world, less costly to produce, apply and are environmentally friendly as they are made of biodegradable material (Bhattacharyya et al., 2008).

Some previous studies have evaluated the effectiveness of erosion control blankets and geotextiles in reducing erosion on roadside slopes and found that they reduce soil loss as a result of improvement in vegetation growth (Bakr et al., 2012; De Oña and Osorio, 2006; Jankauskas et al., 2008; Pengcheng et al., 2008). Bakr et al. (2012) examined the influence of compost/mulch on stormwater runoff rates on highway embankments in Louisiana. They found out that compost/mulch was effective for soil erosion control since it increased crop cover and reduced soil loss. Others such as Pengcheng et al. (2008) evaluated the application of sewage sludge compost on highway embankments in China and observed an improvement of soil quality parameters, increased growth of ryegrass and a reduction in volume of runoff and soil loss. Similarly, Osorio and De Ona (2006) observed that compost application on road embankments in southern Spain increases vegetation cover and reduces soil loss. Additionally, it was found that soil loss decreased with the addition of greater quantities of compost. Jankauskas et al. (2008) investigated the use of palm-leaf geotextiles to control erosion on roadside slopes in Lithuania. They found that soil erosion from bare fallow soil was reduced by 91.15 – 94.8%, and this was attributed to the multiple benefits such as soil conservation and improved soil moisture that encouraged better plant growth.

On the other hand, engineering soil erosion control techniques (e.g. diversion drains and Lattice structures) like non-engineering methods, also reduce erosion on roadside slopes by diverting runoff away from the surface of the roadside slope (Claridge and Mirza, 1981) and intercepting runoff (Xu et al., 2006), respectively. These techniques, however, do not provide a protective layer on the surface of the roadside slope; hence soil detachment from direct rainfall impact could still occur. The combination of engineering and vegetation measures could, therefore, provide an effective method for reducing runoff and direct rainfall impact thereby reducing soil loss on roadside slopes (Xu et al., 2006).

On the basis of the above discussion, the most efficient and economic soil erosion control strategy is re-vegetation. This is because vegetation cover provides a cheap long-term erosion control (Benik et al., 2003), requires less maintenance than complex engineering structures (Montoro et al., 2000) and improves the landscape aesthetic value (Albaladejo Montoro et al., 2000). Hence, soil erosion control through the establishment of a dense vegetation cover is a priority for restoration of roadside slopes (García-Palacios et al., 2010). For instance, Figure 2a illustrates roadside slopes that have successfully stabilized due to the use of vegetation cover as a control mechanism. On the other hand, it can be observed in figure 2b that areas without vegetation cover are prone to erosion. While the use of soil erosion control techniques has been widely recognised and investigated, these investigations have, in most cases, focused on the non-engineering and bio-engineering techniques, and less attention has been given to engineering measures although they could provide an efficient erosion control on roadside slopes (Xu et al., 2006). Therefore, there is a need to test the effectiveness of

engineering measures for erosion control on roadside slopes.

Figure 2. (a) Successful application of vegetation cover to control erosion on a roadside slope and (b) signs of erosion on a roadside slope due to the absence of vegetation cover.

CONCLUSION

Roads and road construction result in soil erosion due to the impacts of rainfall affecting geomorphic and hydrologic processes. Research has shown that the creation of roadcut and fill embankments with steep slopes and little vegetation cover, as well as the concentration of runoff from the road surface and intercepted subsurface flows influence the hydrologic and geomorphic processes. Roadcut embankments, however, are the major sources of erosion than other parts of the road with slope gradient being the most important factor influencing soil erosion. A variety of techniques are used to investigate road-related erosion, ranging from field measurements to soil erosion prediction models. These methods could assist in understanding the nature and severity of road-related erosion and can help guide future development and erosion control efforts. However, besides the strengths of erosion measurement methods, soil erosion prediction models, although appropriate for predicting soil loss for the field plot scale, have challenges when applied to small land parcels. Therefore, there is a need for further testing and modification of soil erosion prediction models for road application.

It has been shown in the literature that soil erosion control techniques have the potential to reduce runoff and soil loss. Numerous studies that have investigated the effectiveness of soil erosion control techniques utilised on roadside embankments showed that the most effective methods are those that promote revegetation and reduce both velocity and quantity of runoff. Since the extent of road networks is ever-increasing, lessons learned from this research may be applied in the future construction of road systems. As such, research still needs to be done (i) to fully understand the underlying determinants of soil erosion related to road design and construction to limit the effect of embankments; (ii) to quantify road-related soil loss; (iii) to evaluate the effectiveness of erosion control methods on both roadcut and fill embankments; and (iv) to identify new approaches such as remote sensing technologies, to try to improve soil erosion mapping along roads for future monitoring and management strategies. This review therefore provides the necessary insight and inspiration to geomorphologists, road engineers and environmentalists to move towards identifying the most suitable, cheap and readily available techniques for assessing and controlling soil erosion, necessary for reliable and informed approaches for monitoring and managing road-related soil erosion across the world, especially in under resourced-countries.

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